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Original articles

Genetics of seed yield and related traits in biparental crosses of okra, *Abelmoschus esculentus* (L.) Moench

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Abstract

Gene action and interaction are very important in formulating the appropriate breeding technique to produce new varieties in okra. The objective of the study was to investigate gene action controlling yield and 12 related traits in okra. Sixteen bi-parental progenies of okra were evaluated in October, 2013 and May, 2014 at the Federal University of Agriculture, Abeokuta (Lat 7°29 N, Long 3°30 E), Nigeria. Seeds were sown in single-row plots laid out in randomized complete block design with three replicates. Mean squares were obtained for the thirteen characters according to North Carolina Design II. Heritable variances were partitioned into additive and dominance components. General (GCA) and specific combining abilities (SCA) of both parental and progenies respectively were estimated with a view to identifying high combiners among genotypes. Results suggested both additive and dominant gene effects for most characters with dominant gene effects for number of leaves per plant and weight of 100 seeds. The study concluded that both additive and dominant gene actions controlled the expression of characters in okra. NHGB/09/009A and FUNAAB-11-8 are high combiners for number of days to 50% flowering and number of pods/plant and they are recommended as high-yielding, early-maturing okra variety. FUNAAB-11-4 x LD 88 and UI4-30 x FUNAAB-11-8 can be further improved to develop high-yielding hybrid okra varieties due to their high SCA. Number of days to 50% flowering, plant height, number of branches per plant, pod weight and number of ridges per pod will respond to selection because of the preponderance of additive gene action.

Keywords: Bi-parental progenies; Gene action and interaction; Combining ability; Additive variance; Dominance variance; Combiner

1. Introduction

Okra, a fruit vegetable, is an annual crop believed to originate from Southeastern Asia. The crop shows preference for the tropical and sub-tropical climates [22], and it is of tremendous significance as a vegetable in these areas [20]. It has a life span of 60–120 days depending upon variety and the main propagules are the seeds. The crop exhibits variable branching, upright and robust stem, growing up to 4 m in height depending on the species. It has alternate leaves that are usually palmately five-lobed, with solitary flowers that are borne on the axils.

Okra flower, being hermaphrodite, self-fertile and self-compatible, ordinarily does not require insects for pollination but the attractive petals invite insects foraging for nectar. Consequently, appreciable level of outcrossing has been obtained in this crop. Chaudhary and Choomsai [3] and Shalaby [25] have reported 4–19% cross-pollination with a maximum occurrence of 42.2% [17].

The production of okra is constantly being constrained by several factors including unimproved cultivars. These often result in reduction of yield and poor quality pods. It is of pertinence, therefore, to develop high-yielding and adaptable okra genotypes that will meet the needs of the people.

Okra yield is dependent on genotype, environment and the interaction of the two. A fundamental aim of any okra improvement strategy should therefore be to come out with superior genotypes that will meet the expectations of the people.

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Gene action explains the manner or mode of expression of genes when they act singly or interact with one another. In breeding, the information on the gene effect in a population helps in the choice of appropriate breeding procedures. The preponderance of a gene effect for a character determined to a large extent how to handle such a character. A ratio of the additive to non-additive variance suggests the relative importance of the gene action controlling the estimates of the character [A ratio above unity (>1) indicates the preponderance of additive variance, whereas, a ratio below unity (<1) indicates non-additive variance [10]].

The concept of general and specific combining abilities (GCA and SCA) was developed by Ref. [28]. Notable relationships have since been established between these two and various heritable variance components [11]. The extent and status of the GCA and SCA show the type of gene action preponderant in a population, and this makes selection among evaluated materials effective. The objectives of this study were to investigate gene action and interaction for yield and related characters in okra as well as the combining ability of eight okra breeding lines for the characters studied in order to formulate appropriate breeding method for okra.

2. Materials and methods

Eight okra breeding lines obtained from breeding programmes of the University were utilized for the study. Four were designated as males and four as females (Table 1) and crosses were made among them following the North Carolina II (NCII) mating scheme [4] to obtain sixteen biparental progenies.

2.1. Hybridization

The hybridization plot was laid out with a row of female parents alternated by a row of pollen parents for ease of crossing. Planting was done in succession to ensure synchronization of flowering. Emasculation was carried out using scarpels and a pair of scissors. Mature flower buds, that would likely blossom the next day, were identified by their prominent and swollen appearance on female parents. Since the receptivity of the stigma is on the day of anthesis, these were emasculated preparatory to hand-pollination the following day. The floral whorls of the flower buds were removed to expose the stigma with the undehisced anthers. Care was taken to avoid injury to the delicate stigma while all the anthers were scraped off using forceps. Before and after emasculation, the forceps and the pair of scissors were dipped in ethanol for sterilization. Emasculation was carried out late in the evening after sunset. The emasculated flower buds were immediately covered up to prevent contamination, and hand-pollination was done very early in the following morning. Previously identified flower buds from designated male parents were plucked just at anthesis to reduce chances of contamination by pollen from unknown sources. Pollen grains from dehisced anthers were carefully dusted on the exposed stigma for pollination and covered up to prevent contamination from foreign pollen. Consequently, tagging of crosses was done appropriately. At maturity, pods from the crosses were air-dried separately and seeds extracted.

Table 1
Names, pedigree, sources and designation of the eight okra parental used for the study.

SN	Accession No	Pedigree	Source	Designation
1	FNB-01	FUNAAB-11-3	PBST, FUNAAB.	Male
2	FNB-02	FUNAAB-11-8	PBST, FUNAAB.	Male
3	FNB-03	FUNAAB-11-6	PBST, FUNAAB.	Male
4	FNB-04	Ld 88	PBST, FUNAAB.	Male
5	FNB-05	FUNAAB-11-4	PBST, FUNAAB.	Female
6	FNB-06	NG/TO/JUN/09/007	PBST, FUNAAB.	Female
7	FNB-07	NHGB/09/009A	PBST, FUNAAB.	Female
8	FNB-08	UI 4-30	PBST, FUNAAB.	Female

PBST = Department of Plant Breeding and Seed Technology, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria.

2.2. Field evaluation of hybrids

The 16 F_1 families obtained were grown in 3.6-m-single-row plots laid out in randomized complete block design (RCBD) with three replications during the late and early planting seasons of 2013 and 2014 respectively at the Federal University of Agriculture, Abeokuta, Nigeria (Lat 7°29 N, Long 3°30 E). Climatological observations for the periods are shown in Table 2. Two seeds were sown and later thinned to one per hole of about 2 cm depth. A spacing of 0.6×0.45 m was employed to give nine stands per F_1 hybrid genotype per replicate and thus maintain a plant density of 37,037 plants per hectare. NPK 20:10:10 was applied at a recommended rate of 60 kg ha^{-1} but split at three weeks after planting and six weeks after planting. A distance of 1 m separated replicates to enhance easy movement during field operations. Weeding was done manually as at when necessary and insect pests were controlled using cypermethrine at the rate of 4 ml/L of water. Biometrical observations began at flowering and were recorded on five middle plants in each row. Table 3 presents the 13 characters and how they were measured. Means of measurements were computed and subjected to analysis of variance following a modification of the general linear model for the NCII [31]. GCA and SCA values for each trait were calculated according to the procedure of Refs. [2] and [31]. Standard errors for the combining ability estimates were determined from the respective mean squares as follows:

$$SEGCA = MSfe/mre \text{ (for females)}$$
$$SEGCA = MSme/fre \text{ (for males)}$$
$$SESCA = MSfme/re$$

Where:MSfe, MSme and MSfme are females $\times$ environments, males $\times$ environments and females $\times$ males $\times$ environments mean squares respectively.

The significant differences of the GCA and SCA values from zero were tested using the two-tailed t-test ($P \leq 0.05$).

Table 2
Means of agrometeorological observation for the two planting periods.

Month	October, 2013	November, 2013	December, 2013	May, 2014	June, 2014	July, 2014
Max temp °C	31.7	33.1	33.0	32.1	31.5	29.9
Min temp °C	23.1	23.5	22.4	23.4	23.4	23.3
Mean temp °C	27.0	28.3	27.2	27.8	27.5	26.6
Total rainfall (mm)	94.4	15.6	16.5	113.8	116.5	90.7
Relative humidity (%)	67.2	60.0	58.5	66.7	64.4	69.8
Sunshine (Hours)	5.0	6.5	6.2	5.8	5.9	3.8
Evaporation (mm)			4.1			
Soil temp °C:						
10 cm	2.4	4.2	27.7	3.1	2.3	1.3
20 cm	27.4	27.7	28.1	29.0	28.2	27.7
30 cm	27.7	28.0	28.8	28.5	28.5	27.9
50 cm	28.1	29.3	29.4	31.8	29.1	24.1

Source: Dept of Agrometrology and Water Resources Management, Federal University of Agriculture, Abeokuta, Nigeria. (2014).

Table 3
List of observations and method of measurement.

Sn	Character	Method of determination
1	Number of days to 50% flowering	The number of days taken from the date of sowing to the day on which 50 percent of the genotype population in a row flowered
2	Final plant height (cm)	This was measured from the base of the plant to the tip of the plant at maturity
3	Stem girth (cm)	Measured as the thickness of the main stem, taken approximately 2 cm from soil level
4	Number of leaves per plant	Taken by physically counting the number of leaves, including nodes of shed leaves at plant maturity
5	Number of branches per plant	Taken by counting the number of main branches at plant maturity
6	Number of pods per plant	Taken by physically counting the pods on the main stem and the branches at maturity
7	Pod weight (g)	Taken as the average weight of ten randomly selected dry pods
8	Pod length (cm)	Taken as the distance from the base of the calyx to the tip of the pod of ten randomly selected dry pod
9	Pod width (cm)	Taken as average diameter of ten randomly selected dry pod
10	Number of ridges per pod	Taken by as the average number of ridges counted on ten randomly selected pods
11	Number of seeds per ridge	Taken as the average number of seeds counted in ten randomly selected pods
12	Number of seeds per pod	Taken as the average number of seeds counted in ten randomly selected pods
13	One hundred seed weight (g)	Taken as the average weight of 100 seeds randomly picked from the bulked seeds of each genotype in each replication

Estimates of genetic components for each character were determined according to the procedure of Ref. [27].

3. Results

The analysis of variance for all the traits observed in respect of NCII is presented in Table 4. There were highly significant ($p \leq 0.01$) environmental effects for all the characters except number of ridges per pod. Both female and male effects were significant for plant height, number of branches per plant, number of pods per plant and seed yield per plant. However, only female effect was significant for number of days to 50% flowering, pod weight and number of ridges per pod while male effect was significant for number of seeds per ridge and number of seeds per pod. Significant female × male effect was observed for all the traits considered except stem girth, pod length and pod width. Significant environment x female and environment × male interactions effect was observed with respect to number of pods per plant, 100-seed weight and seed yield per plant. Environment × female interaction effect was found to be significant for number of days to 50% flowering, number of leaves, pod weight and number of seeds per pod. Furthermore, significant environment × male interaction effect was observed for plant height, number of branches per plant and number of ridges per plant while environment x female × male interaction effect was found to be significant with respect to number of days to 50% flowering, plant height, number of leaves per plant, number of branches per plant, number of pods per plant, pod weight and seed yield per plant.

Table 5 shows estimated genetic parameters of biparental population arising from NCII mating of okra. It was observed that additive variances were generally lower than corresponding dominance variances for all the characters. Genotypic variances were relatively higher compared to phenotypic variances leading to generally high broad-sense heritability. The values of GCV ranged from 6.62% for number of days to 50% flowering to 90.75% obtained for seed yield per plant. PCVs were higher than GCVs in all cases with a minimum of 6.79% for number of days to 50% flowering and a maximum of 91.70% for seed yield per plant. Narrow-sense heritability was generally low for all the characters studied. The highest estimate of 22.78% was obtained for plant height and the lowest of 0.03% for number of leaves per plant. However, estimates of broad-sense heritability were generally high (>70%) with seed yield per plant exhibiting the highest value of 97.92% while stem girth had the lowest of 65.19%.

Estimates of specific combining abilities (SCA) of the sixteen crosses are presented in Table 6. Significant positive

Table 4
Analysis of Variance of North Carolina Design II for 16 F_1 Hybrids of okra in the two environments.

Source	df	50%F	PtH	StG	NoL	NoB	Pd/Pt	PodWt	PdL	PdWdth	Rg/Pd	Sd/Rg	Sd/Pd	100-Sd wt	SdYld
Environment	1	450.67**	72317.58**	44.79**	5583.79**	62.24**	2397.00**	1698.40**	457.19**	26.82**	1.08	1157.90**	78627.15**	24.49**	131548.98**
Block	2	5.40	24.68	0.80	27.90	0.55	2.98	1.76	2.17	0.11	1.08	4.81	231.70	0.00	158.69
Female (F.)	3	18.57**	486.95**	0.28	63.81	2.21**	56.43**	13.67**	4.65	0.09	3.58**	8.51	613.06	0.29	4594.18**
Male (M.)	3	9.57	1859.65**	0.08	69.19	2.53**	11.00**	4.31	3.98	1.02	0.99	18.57*	3342.61**	1.00	2580.81**
F x M	9	13.47**	238.57**	0.05	66.72**	1.57**	20.22**	6.54**	1.11	0.42	1.23**	10.00*	1059.58**	0.64*	1905.99**
Env. x F.	3	16.03**	110.30	0.06	98.79**	0.21	43.69**	15.32**	0.77	0.09	0.80	1.72	914.40*	3.33**	4148.73**
Env. x M.	3	8.92	1332.06**	0.06	67.24	1.55*	5.06**	5.79	1.54	0.09	0.10**	2.89	897.29	2.22**	2006.12**
Env. x F x M	9	6.46*	423.22**	0.10	75.23**	1.95**	18.45**	5.25**	1.11	0.36	1.01	8.02	167.53	0.17	1629.93**
Error	62	1.44	50.98	0.06	10.38	0.20	1.18	0.93	0.71	0.15	0.21	2.41	135.83	0.15	86.98

** and * significant at 1% and 5% probability levels respectively.
50% F = Number of days to 50% flowering; PtH = Plant height (cm); StG = Stem girth (cm); NoL = number of leaves per plant; NoB = Number of branches per plant; Pd/Pt = number of pods per plant; PodWt = Pod weight (g); PdL = Pod length (cm); PdWdth = Pod width (cm); Rg/Pd = number of ridges per pod; Sd/Rg = Number of seeds per ridge; Sd/Pd = Number of seeds per pod; 100-Sd wt = weight of 100 seeds (g); SdYld = Seed yield per plant (g).
Env. × F. = Environment × Female interaction; Env. × M. = Environment × Male interaction; Env. × F. × M. = Environment × Female × Male interaction.

Table 5
Genetic components of biparental population arising from NCII.

	50%F	PtH	StG	NoL	NoB	Pd/Pt	PodWt	PdL	PdWdth	Rg/Pd	Sd/Rg	Sd/Pd	100-Sd	SdYld
δ^2a	0.03	51.93	0.01	0.01	0.04	0.75	0.14	0.18	0.01	0.06	0.20	51.01	0.00	93.42
δ^2d	8.98	159.05	0.03	44.48	1.05	13.48	4.36	0.74	0.28	0.82	6.67	706.39	0.43	1270.66
δ^2e	0.48	16.99	0.02	3.46	0.07	0.39	0.31	0.24	0.05	0.07	0.80	45.28	0.05	28.99
δ^2g	9.01	210.98	0.04	44.50	1.09	14.23	4.50	0.92	0.29	0.88	6.86	757.40	0.43	1364.08
δ^2p	9.49	227.97	0.06	47.95	1.16	14.62	4.81	1.16	0.34	0.95	7.67	802.68	0.48	1393.07
δ^2gca	0.01	12.98	0.00	0.00	0.01	0.19	0.03	0.04	0.00	0.01	0.05	12.75	0.00	23.35
δ^2 sca	4.49	79.52	0.02	22.24	0.52	6.74	2.18	0.37	0.14	0.41	3.33	353.19	0.21	635.33
GCV	6.62	21.94	12.03	32.45	73.88	57.60	24.76	11.28	21.71	13.36	26.28	37.44	11.59	90.75
PCV	6.79	22.80	14.90	33.69	76.10	58.38	25.60	12.65	23.56	13.89	27.77	38.54	12.27	91.70
Hb (%)	94.96	92.55	65.19	92.79	94.26	97.32	93.53	79.51	84.91	92.57	89.51	94.36	89.35	97.92
Hn (%)	0.35	22.78	12.14	0.03	3.81	5.13	2.83	15.39	2.17	6.20	2.57	6.36	0.04	6.71
GA (% of mean)	13.29	43.47	20.01	64.40	147.76	117.04	49.33	20.72	41.22	26.48	51.21	74.91	22.58	184.98

δ^2a = additive variance; δ^2d = dominance variance; δ^2e = environmental variance; δ^2g = genotypic variance; δ^2p = phenotypic variance; δ^2gca = gca variance; δ^2sca = sca variance; GCV = genotypic coefficient of variation; PCV = phenotypic coefficient of variation; Hb = broad-sense heritability; Hn = narrow-sense heritability; GA = genetic advance.
50% F = Number of days to 50% flowering; PtH = Plant height (cm); StG = Stem girth (cm); NoL = number of leaves per plant; NoB = Number of branches per plant; Pd/Pt = number of pods per plant; PodWt = pod weight (g); PdL = Pod length (cm); PdWdth = Pod width (cm); Rg/Pd = number of ridges per pod; Sd/Rg = Number of seeds per ridge; Sd/Pd = Number of seeds per pod; 100-Sd wt = weight of 100 seeds (g); SdYld = Seed yield per plant (g).

SCAs were obtained for a number of crosses with respect to all the characters except number of branches per plant for which all the crosses showed significant negative combining abilities. For earliness to flower, the most favourable SCA (−2.35) was obtained in FNB-08 x FNB-04. FNB-08 x FNB-02 expressed the highest favourable SCA (5.10) for number of pod per plant while FNB-06 x FNB-01 showed the least (0.31). Crosses FNB-05 x FNB-01 and FNB-06 x FNB-03 also exhibited significant and favourable SCAs of 2.19 and 1.65 respectively, for this character. For plant height, the most favourable and significant SCA was observed in FNB-07 x FNB-01 (9.37). This was followed closely by FNB-08 x FNB-03 with an SCA of 8.73. Highly significant estimates of combining ability were also found among the crosses for seed parameters. FNB-05 x FNB-04 was found to be very promising over number of seeds per pod and seed yield per plant with SCAs of 21.02 and 19.66 respectively. For seed yield per plant, the specific combining abilities of the sixteen hybrid genotypes ranged from 2.82 to 33.23 with FNB-08 x FNB-02 showing the highest estimate followed by FNB-05 x FNB-04 (19.66) while FNB-07 x FNB-03 exhibited the least value (2.82).

Table 7 shows values of general combining abilities of the four female and four male parent genotypes used for the fourteen characters. No parent had consistently high general combining abilities for all fourteen characters considered. However, genotypes FNB-04 and FNB-05 showed high combining abilities for number of seeds per pod (16.34 and 7.29 respectively) and seed yield per plant (14.19 and 15.86 respectively). FNB-04 proved promising for use in recombination breeding for earliness to flowering with its significant negative general combining ability of 0.94 for this trait. Only FNB-01 showed significant ($P \leq 0.05$) general combining ability (0.27) for pod width.

Table 6
Estimates of specific combining abilities of sixteen crosses of okra.

Cross	50%F	PtH	StG	NoL	NoB	Pd/Pt	PodWt	PdL	PdWdth	Rg/Pd	Sd/Rg	Sd/Pd	100-Sd	SeedYld
FNB-05 X FNB-01	−1.69*	−7.44	0.03	0.34	−2.62**	2.19**	1.07	−0.22	−0.40	−0.73**	0.58	−8.58	0.15	10.01
FNB-05 X FNB-02	1.15	4.88	0.03	−5.03**	−2.97**	−2.48**	−0.83	0.23	0.25	0.47	−1.67	−10.13	−0.28	−21.59**
FNB-05 X FNB-03	−0.06	1.76	0.10	2.40	−2.89**	−0.90	0.36	0.07	0.18	0.09	0.30	−2.32	0.30	−8.08
FNB-05 X FNB-04	0.60	0.76	−0.16	2.28	−2.84**	1.19	−0.60	−0.08	−0.02	0.16	0.79	21.02**	−0.17	19.66**
FNB-06 X FNB-01	−0.98	0.00	0.00	−0.08	−3.25**	0.31	0.21	−0.03	0.01	−0.25	0.02	−0.77	−0.15	3.68
FNB-06 X FNB-02	0.19	2.16	0.04	1.37	−2.78**	−1.76**	0.35	0.59	0.29	−0.19	0.15	0.41	0.34	−7.97
FNB-06 X FNB-03	−0.69	−3.83	−0.11	0.45	−2.97**	1.65**	0.75	−0.33	−0.18	0.13	−0.21	4.89	0.03	9.87
FNB-06 X FNB-04	1.48*	1.62	0.07	−1.74	−2.32**	−0.20	−1.31*	−0.23	−0.11	0.31	0.04	−4.54	−0.23	−5.59
FNB-07 X FNB-01	0.65	9.47*	0.03	4.03*	−2.03**	−3.83**	−0.23	0.57	0.27	0.43	1.57	20.62**	0.39	4.92
FNB-07 X FNB-02	−0.69	−1.33	−0.02	0.34	−3.17**	−4.61**	0.24	−0.46	−0.25	−0.20	0.26	−2.13	−0.16	−3.67
FNB-07 X FNB-03	−0.23	−6.70	−0.04	−3.36	−2.60**	−3.09**	−0.23	0.00	−0.06	−0.25	−0.80	−6.75	−0.32	2.82
FNB-07 X FNB-04	0.27	−1.49	0.03	−1.00	−3.52**	−3.47**	0.21	−0.11	0.04	0.02	−1.03	−11.74	0.09	−4.07
FNB-08 X FNB-01	2.02**	−2.08	−0.06	−4.29*	−3.42**	−2.42**	−1.06	−0.32	0.13	0.55*	−2.17*	−11.28	−0.40	−18.62**
FNB-08 X FNB-02	−0.65	−5.75	−0.05	3.33	−2.40**	5.10**	0.24	−0.36	−0.29	−0.09	1.26	11.84	0.10	33.23**
FNB-08 X FNB-03	0.98	8.73*	0.05	0.51	−2.86**	−1.41*	−0.88	0.26	0.07	0.03	0.71	4.18	−0.02	−4.61
FNB-08 X FNB-04	−2.35**	−0.94	0.06	0.45	−2.64**	−1.26*	1.70**	0.43	0.09	−0.49	0.20	−4.74	0.31	−10.00
LSD (0.05)	1.38	8.19	0.29	3.70	0.51	1.24	1.11	0.97	0.45	0.53	1.78	13.37	0.45	10.70

** and * significance at 1% and 5% probability levels respectively.
50% F = Number of days to 50% flowering; PtH = Plant height (cm); StG = Stem girth (cm); NoL = number of leaves per plant; NoB = Number of branches per plant; Pd/Pt = number of pods per plant; PodWt = pod weight (g); PdL = Pod length (cm); PdWdth = Pod width (cm); Rg/Pd = number of ridges per pod; Sd/Rg = Number of seeds per ridge; Sd/Pd = Number of seeds per pod; 100-Sd wt = weight of 100 seeds (g); SdYld = Seed yield per plant(g).

Table 7
Estimates of general combining abilities of eight parental genotypes of okra used for the study.

Female	50%F	PtH	StG	NoL	NoB	Pd/Pt	PodWt	PdL	PdWdth	Rg/Pd	Sd/Rg	Sd/Pd	100-Sd	SeedYld
FNB-05	−0.35	−1.35	0.13	−1.32	0.42**	1.23**	0.61*	−0.05	−0.04	−0.18	0.24	7.29*	0.14	15.86**
FNB-06	−0.56	−5.76*	0.04	−1.50	−0.30*	0.58	0.44	0.60*	−0.03	−0.46**	0.73	−0.56	−0.09	4.36
FNB-07	1.31**	3.05	−0.07	1.46	−0.12	1.46**	−1.07**	−0.46	−0.02	0.36**	−0.50	−2.81	0.04	−17.17**
FNB-08	−0.40	4.06	−0.11	1.36	0.00	0.48	0.02	−0.10	0.09	0.28*	−0.47	−3.91	−0.09	−3.06
Male														
FNB-01	0.19	−7.08*	−0.03	−0.99	−0.10	−0.63*	−0.25	−0.51*	0.27*	0.04	−0.28	−2.92	−0.05	−3.00
FNB-02	0.35	2.77	−0.02	1.77	0.05	0.92**	−0.27	0.46	−0.19	−0.03	0.22	−1.61	−0.22*	−0.61
FNB-03	0.40	−6.94*	−0.03	−1.84	−0.36**	−0.87**	−0.11	−0.08	0.04	−0.25	−1.02*	−11.81**	0.27*	−10.58**
FNB-04	−0.94**	11.25**	0.08	1.07	0.41**	0.58*	0.63*	0.12	−0.13	0.24	1.08*	16.34**	0.00	14.19**
EMS	1.44	50.98	0.06	10.38	0.20	1.18	0.93	0.71	0.15	0.21	2.41	135.83	0.15	86.98
LSD (0.05)	0.69	4.10	0.14	1.85	0.26	0.62	0.55	0.48	0.22	0.26	0.89	6.69	0.22	5.35

** and * significance at 1% and 5% probability levels respectively.
50% F = Number of days to 50% flowering; PtH = Plant height (cm); StG = Stem girth (cm); NoL = number of leaves per plant; NoB = Number of branches per plant; Pd/Pt = number of pods per plant; PodWt = pod weight (g); PdL = Pod length (cm); PdWdth = Pod width (cm); Rg/Pd = number of ridges per pod; Sd/Rg = Number of seeds per ridge; Sd/Pd = Number of seeds per pod; 100-Sd wt = weight of 100 seeds (g); SdYld = Seed yield per plant(g).

4. Discussion

The success of any crop improvement effort depends on potentials inherent in the available genetic materials and the possibility of selection among such potentials. Selection is the backbone of breeding and this is possible only where there is diversity or variation in observable characters. The observed significant differences in female and male effects implied that there was sufficient additive variation among the parents to enhance improvement through selection. This agrees with the submissions of Refs. [1] and [8] that okra has many genotypes each with distinct characters. Hammond and Charrier [12] had earlier reported wide diversity, especially with regards to pod shape in West African okra accessions. The significant female × male interaction also indicated that there was dominance variance. This implied that sufficient genetic diversity was created through recombination and there is possibility of improvement through recombination breeding. The varied extent of variation of the characters across the two environments may be due to genotype × environment interaction. The significance of both or either of environment × female and environment × male interaction effects for all the characters except stem girth, pod length, pod width and number of seeds per ridge indicates that the genotypes performed differently from one environment to the other with respect to these characters, and as such, phenotypic estimates of these characters in just one environment may not be a good index of genotype.

Both additive and dominant variances were recorded for all the characters studied. However, the dominance variances were higher than the additive variances for all the characters indicating the repeatability of relation. These characters can thus be improved through recombination. Similar findings have been made by several researchers such as [15] who observed the importance of both additive and non-additive components of heritable variance conditioning plant height, number of branches per plant, inter-nodal length, first flowering node and marketable yield per plant in okra. Reddy et al. [23] reported similar results for number of days to 50% flowering, plant height, fruit length, fruit weight and number of fruits per plant in okra. Comparable results were also reported by Dahake and Bangar [5] and Jaiprakashnarayan et al. [14] for number of number of days to 50% flowering, by Jaiprakashnarayan et al. [14] for fruit weight and by Kumar et al. [16] for first fruiting node, fruit length and width, total number of fruits per plant and total yield per plant of okra.

Expectedly, phenotypic variances were higher than genotypic variances for all the characters studied. However, the genotypic values were quite close to the phenotypic values indicating little influence of environment in the expression of genotype. Hence, any selection made on the basis of the phenotype will likely be reliable and effective. GCA variances were consistently lower than corresponding SCA variances for all the characters. This corroborated earlier finding that there was preponderance of dominance variance in this study. The magnitude of SCA variance greater than that of GCA variance points to the predominance of the non-additive gene action for all the characters. Kumar et al. [16] and Reddy et al. [21] made similar observations in okra for plant height, fruit length, fruit width and number of days to 50% flowering.

Estimates of genotypic (GCV) and phenotypic coefficients of variation (PCV) revealed that both values were high for number of leaves per plant, number of branches per plant, number of pods per plant, number of seeds per ridge, number of seeds per pod and seed yield per plant. This is an indication of high variability for these traits [19,29]. Values of phenotypic coefficients of variation were higher than their corresponding genotypic values and this would probably implicate the environment. The high variability coupled with high broad-sense heritability suggests that phenotype-based selection should be reliable and effective. However Dhankhar and Dhankar [6], have argued that heritability (especially broad-sense heritability) alone may be misleading and so should be jointly considered with genotypic coefficient of variation and genetic advance. And, according to Ibrahim and Hussein [13] and Nwangburuka et al. [19], characters with high heritability as well as genotypic coefficient of variation and genetic advance, such as obtained for number of leaves per plant, number of branches per plant, number of pods per plant, number of seeds per ridge, number of seeds per pod and seed yield per plant in this study, can be explained by additive gene action and hence can be improved through mass selection. Such characters, according to [18]; may be good predictors of yield.

In biometrical genetic research, two types of combining ability are recognized. These are general combining ability and specific combining ability. While general combining ability is the average performance of a line across a number of crosses, specific combining ability is the deviation in the performance of a hybrid from the average performance of the parents from which it was obtained. General combining ability is due to additive effects of genes while specific combining ability is due to dominance and/or epistatic effects of genes. The direction and extent of combining ability effects of the eight parents and 16 progeny families varied significantly except for number of branches per plant for which all the SCAs were negative. Parents with high GCAs can be improved through mass selection while those with high SCAs for yield-contributing traits could be used for heterosis breeding. For earliness to flowering, parents and crosses with negative significant GCAs and SCAs respectively can be considered for improvement. The marked GCA effects for all the characters except stem girth and number of leaves per plant implicated the dominance of additive gene action in determining the expression of the characters. Similar results have been obtained for economic traits in okra by Ref. [30]. According to [26]; high GCA effects are attributable to additive or additive × additive gene interaction effects, which represent the fixable genetic components of heritable variance. Hence, parents with high GCA effects may be used in a multiple crossing program for isolating desirable lines in okra, and the isolated lines could be released as conventional varieties or used as improved parents for F_1

hybrid production. The direction of GCAs of FNB-03 (−) and FNB-04 (+) for seed yield per plant is the same as the direction of their GCAs for all the yield-contributing characters except pod width and number of days to 50% flowering for FNB-04 and 100-seed weight, pod width and number of days to 50% flowering for FNB-03. Comparable findings were reported by Refs. [21] and [24]. This suggests that high GCAs for these characters can serve as a pointer for high GCA for yield in okra.

5. Conclusion

There was sufficient genetic diversity among the parents and crosses for selection to be effective. Both additive and dominant gene actions were involved in the phenotypic expression of all the characters considered in this study. However, dominant gene action is more important in the inheritance of all the characters in okra population used for this study. Furthermore, the hybrids responded to environmental influences in their phenotypic expression of characters, except for stem girth, pod length, pod width and number of seeds per ridge. Among the crosses, there is substantial combining ability for various important characters of okra with FNB-08 x FNB-01 and FNB-06 x FNB-04 promising for early flowering and may be useful to developing early-flowering okra varieties. FNB-05 x FNB-01, FNB-06 x FNB-03 and FNB-08 x FNB-02 were the best combiners for number of pods per plant. FNB-02 x FNB-04 and FNB-08 x FNB-02 also showed potentials to be useful in developing prolific varieties in terms of seed yield because of their high specific combining ability for the trait. FNB-04 is a high general combiner for number of days to 50% flowering, number of branches per plant, number of seeds per ridge and number of seeds per pod while FNB-07 is promising for number of pods plant. Being a high combiner for number of branches per plant, number of pods per plant and number of seeds per pod, FNB-05 can be utilized to harness the additive gene action for improvement of okra with respect to these characters.

Consequently, number of days to 50% flowering, plant height, number of branches per plant, pod weight and number of ridges per pod are recommended for selection because of preponderance of additive gene action. Also, number of leaves per plant and 100-seed weight should be selected for, to harness the dominance gene action for hybrid okra production.

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